THE CARNEGIE MELLON TRUCKSIM: A TOOL TO IMPROVE DRIVING SAFETY

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Abstract

Carnegie Mellon Driving Research Center is presently involved in the design and development of an Advanced Human Factors Research and Driving Training Research Facility. The facility has been designed to address human factors issues and driver training issues. Human factors interests include developing countermeasures for fatigue and driver/vehicle interface issues. Driver training issues include validating the usefulness of simulators for driver training, developing effective curricula and investigating simulator fidelity needed for effective training. A key component of the facility is the Carnegie Mellon TruckSim that will be capable of simulating a variety of commercial and emergency vehicles using interchangeable cabs mounted to a common motion platform. TruckSim's modular configuration will allow for rapid and cost effective design of experiments and training scenarios. A first research program to evaluate fatigue countermeasures is presented as an example.

Introduction

The Carnegie Mellon Driving Research Center (DRC), working together with ISIM Corporation, has designed and developed TruckSim, a state-of-the art driving simulator specifically designed for human centered research. TruckSim has been designed to provide a realistic driving experience. A key design criteria is a balanced perceptual environment with realistic visual, motion/vibration and sound cues.

TruckSim, as its name suggests, is currently configured as a Class 8 truck with a Freightliner FLD cab. The configuration was chosen to advance DRC's ongoing research in the heavy truck area. However, TruckSim has been designed to be reconfigurable in order to simulate a variety of vehicles including passenger cars, buses and off-road vehicles. Each cab/body to be used on the simulator is equipped with a dedicated sound system plus sensor; and actuators associated with the driver controls and displays. A truck cab/body is bolted to the motion base and integrated to the simulation control station through a set of quick connect plugs.

TruckSim also includes a user friendly experimenter console. Using the console, an experimenter can rapidly and cost effectively implement complex experimental designs. The easy to use graphical user interface allows the experimenter to precisely control the interaction of the simulated vehicle with over 100 additional vehicles or pedestrians. A behavioral scientist with little or no programming experience can really use this

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intuitive interface.

TruckSim can be used for a wide variety of research programs.

Important classes of research problems that can be studied in simulation are:

Driver Training

- Commercial driver training
  - Novice driver training
  - Driver retraining (continuing education)
- Young driver training
- Older driver training/evaluation

Driver Workload

- Visual allocation/distraction/demand
- Manual demand
- Cognitive load assessment
- Information prioritization

Infrastructure

- Road signing/traffic advisory
- Automated highway/Intelligent Transportation System
- In-vehicle signing

Driver Impairment

- Drowsiness detection and warning
- Drug/alcohol effects
- Age effects
- Rehabilitation testing

Vehicle Design

- Display design
- Control Design
- Warning/emergency evaluation
- Equipment design
- Interface optimization

Simulator Fidelity

- Simulator sickness

All of these listed areas are of potential interest and may be addressed in the future using the TruckSim. To address a wide range of research topics the TruckSim is available to the research community on an hourly-fee basis.

Simulator Technology

There is no question that simulation is being used effectively today. But with certain technical advances and more emphasis on behavioral factors, simulation offers the potential for making even greater contributions at a significantly lower cost than previously possible. In the past, the importance of the relationship between how a simulator is used and its effectiveness has not been fully appreciated. As a consequence, simulators are often not as versatile or cost-effective as they could be. The contributions that behavioral science and human factors engineering has made to the design and use of simulators is underrepresented.

In the past, ground-vehicle simulators were not flexible enough to allow for rapid reconfiguration necessary to efficiently evaluate new transportation technology or cost effective training. As the rate of new systems development increased over the years, it became important to be able to rapidly simulate and test these systems. The CMRI team has formulated the design for a facility that provides cost-effective and rapidly configurable operator-in-the-loop simulation for use in basic and applied research.

Simulator Design

The TruckSim design is based on the ISIM Mark II simulator. Additions/upgrades of the Mark II design include improved visual resolution an enhanced four degree of freedom motion base and the addition of Eaton programmable transmission simulator, and the addition of the experimenter's console. See figure 1 for the simulator configuration.

- Insert Figure 1 here -

Figure 1: Carnegie Mellon TruckSim ©

The simulator's design includes:

Visual System

- Angular field of view - 180 degrees horizontal, 33 degrees vertical
- Forward display channels - 3 channels, 1000 x 800 pixel resolution
- Brightness of forward channel projectors - 300 lumens
- Rear display channels type - 2 channels, 600 x 480 pixel resolution, flat panel
- Minimum screen drawing rate - 30 Hz
- Anti-aliasing - implemented in hardware
- Projector position - inside of screens
- Number of moving vehicles per channel - 100

Motion System

- Motion platform degrees of freedom - 4 - roll, pitch, surge and heave
- Roll angular amplitude and acceleration - ± 6 degrees, 1 G maximum acceleration
- Pitch angular amplitude and acceleration - ± 6 degrees, 1 G maximum acceleration
- Surge linear amplitude and acceleration - 0.1 meters, 0.5 G maximum acceleration
- Heave linear amplitude and acceleration - 0.1 meters, 0.5 G maximum acceleration
- Small amplitude bandwidth - 15 Hz
- Maximum latency of motion system - 50 milliseconds
- Motion simulation capabilities - road surface irregularities (i.e., potholes, rumble strips, uneven road surface), off road surfaces (i.e., curb, soft shoulder, driving off road surface), tactile response for multiple tire types

Audio System

- Number of sound channels - 4
- Sound simulation capabilities - multiple tire type sounds, velocity dependent wind noise, transmission grinding cue, additional sounds can be added

Other Features

- Transmission simulation type capabilities - Eaton / gate lockout, manual grinding feedback
- Steering wheel bandwidth - 20 Hz
- Operator capabilities - scenario editing, playback, scoring
- Vehicle dynamics model - operator adjustable, including 3D tire model
- Road data base - configurable data base including urban, rural, mountains, highway scenes

Traffic Control

- Number of traffic objects - over 100 objects (vehicles, pedestrians, etc.)
- Automated intelligent traffic control - control of traffic density, aggressiveness, circulatory and Swarm traffic
- Scenario controlled traffic - Specific actions of any of the traffic objects can be specified using a windows based GUI.
- Operator controlled traffic - The operator can also take control of any traffic object.

TruckSim's visual system provides a forward field of view and two sideview mirror views. The forward field of view is implemented with three LCD projectors each providing 1200 x 1000 pixel resolution within each 60° of view. The sideview mirrors are implemented in LCD displays. The visual data base consists of a 21 mile 4-6 lane highway loop, a 9 block urban setting, and a rural setting. The driver can move seamlessly throughout the data base.

The motion system includes a four degree of freedom motion platform. The motion platform includes independent actuators for roll, pitch, surge and heave. Independent actuation was used in order to enhance the high frequency performance so important in achieving good road feel. The motion platform is capable of simulating road surface irregularities such as potholes, rumble strips, uneven road surfaces, curbs and driving off road.

A vital part of TruckSim's excellent road feel is the implementation of a true three dimensional tire model. The road/tire interacts at a 1000 Hz rate allowing inclusion of fine road irregularities such as pot holes and rumble strips.

The system architecture is shown in Figure 2. All simulator control and the operator interface are contained in a dual Pentium Pro PC, four Real 3D 1000 image generators are employed to generate the visual scene, a Pentium PC is employed for the experimenter's console. All sensors and actuators are integrated directly into the dual Pentium Pro. Communication among the systems is accomplished using a 100 baseT ethernet.

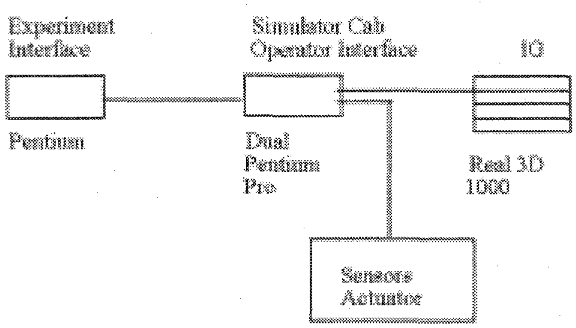

Figure 2: System Configuration.

- ***Multiple Vehicle Simulation.*** The simulator accepts a variety of vehicle bodies on the motion base. In addition, the modular software design allows for rapidly changing the vehicle dynamics software without disturbing the remainder of the system.

- ***Simple Experimental Design and Execution.*** A number of features have been included to facilitate experimental setup. A scenario builder allows the experimenter to define driving scenarios using a point and click interface. Data associated with these scenarios have been selected for collection and analysis using this package. In addition, methods for time synchronizing auxiliary data collection devices such as video tapes, physiological data and event strobing have been provided by the TruckSim.

The proper design of these components is largely based on expert front-end analysis. Since this process required considerable specialized effort, the CMRI team was successful because of their relevant area of expertise. Physical requirements for simulators cannot be considered in isolation because they interact with the way a device is used. The team utilized their depth of knowledge concerning the nature of these use factors and their interactions with equipment factors as a basis for simulator design within the facility.

Research Example: Drowsy Driver Study

An area currently under investigation involves detecting drowsiness and warning or alerting drivers of heavy vehicles in order to prevent costly accidents due to fatigue. An investigation of fatigue lends itself to simulator research. It is possible to simulate the conditions under which a driver would be likely to be drowsy without posing a hazard on the actual roadways. Specific details of one ongoing experiment are described below.

Background

This experiment has been designed to stress the effect of feedback to drivers experiencing drowsiness while driving the TruckSim. The feedback to be considered is:

- Information feedback
- An audible alarm
- Alerting Stimuli: olfactory stimulus and auditory stimulus

The objectives of this study are:

- To determine if the above feedback promotes arousal of the driver.
- To determine the driver's behavioral response to the feedback related to rest breaks and safe driving practices.

Proposed Experiment

The study goal is to test the effects on drivers' drowsiness (as defined by PERCLOS) and driving behaviors of a drowsy-driver detection system that includes a PERCLOS detector and algorithm coupled with a drowsiness/alertness gauge containing an audio and visual alarm, which in turn is coupled to one of two alerting stimuli: (A) a peppermint or menthol olfactory stimulus (specific type to be determined); and (B) an auditory alert command that the driver take countermeasure action immediately. The alerting stimuli will be delivered only after drowsiness has been presented for a sustained period of time (to be determined). The study will be implemented and performed using a total of 16 drivers.

All 16 subjects will undertake a 6-hr nighttime driving scenario on two separate occasions (serving as their own controls and counterbalancing for order conditions). These two drives will be performed using the Carnegie Mellon Research Institute truck simulator (CMRI TruckSim), and will occur in the morning (starting at approximately 0600hr to 0800hr) after drivers have completed a standard out-and-back, short-haul overnight drive for the company. This will ensure that drivers are performing in the simulator after a minimum of 12 hr awake, and near their circadian time for vulnerability to drowsiness. This approach is expected to produce drowsiness episodes in most, if not all drivers. However, since the magnitude and duration of these drowsiness episodes are not under full experimental control, and given the sample size of n = 16 drivers, it is imperative that there be a minimum sampling period of at least 3 hr during the treatment nighttime drive, to ensure that there is an adequate time base in which to capture drowsiness episodes and record driver responses (drowsiness and behaviors) to the two types of alerting stimuli.

Alerting stimuli are not considered at the same level as visual feedback on drowsiness. Rather, there is a progression from alerting stimuli. There is a very high potential for driver dissatisfaction with a system in which alerts are always paired immediately with detection of drowsiness, given the likely problems of false alarms, habituation to auditory and/or olfactory stimulation, and driver annoyance with repeated alerts. Therefore it is simply not realistic to expect that the final drowsy-driver on-line technology will function by attempting to arouse a driver every time drowsiness is detected. It is far more likely that, like other warning displays in a motor vehicle, the first acceptable mode for feedback regarding drowsiness detection will be a visual signal informing the driver that drowsiness is detected. Its purpose is to inform and prompt a self-directed change in driver behavior. Only after such self-initiated change is not undertaken, and drowsiness continues for a period of time deemed increasingly riskier, would one expect another level of feedback—namely that of arousal induction by alerting stimuli.

There is a logical progression from visual information feedback that drowsiness is detected, to alerting stimuli when drowsiness is sustained (i.e., an alerting stimulus only occurs after alarm feedback that unacceptably high levels of drowsiness has been present for some period of time). Thus, alerting stimuli will be contingent on a high level of drowsiness being sustained for (too) long a period, which will be predetermined, but is expected to be on the order of 5 to 10 minutes. This will permit assessment of the main effects on dependent variables of (1) visual feedback versus no visual feedback (n = 16); and (2) of the effects of an alerting auditory stimulus versus an alerting olfactory stimulus.

The specific conditions of the study are as follows:

Half of the subjects will undergo the control condition first and the intervention condition second, and half will undergo the intervention condition first and the control condition second.

In the intervention condition, all subjects will experience a visual gauge plus an auditory alarm for drowsiness with progression to an alerting stimulus.

Half of the subjects (8 drivers) will be exposed to the auditory alerting stimulus ("Take corrective action") on the outbound half of their drive, and the olfactory stimulus on the inbound half of their drive. Of these eight, half (n = 4) will experience this condition during the first nighttime drive and the remaining half (n = 4) will experience it during the second nighttime drive.

The other half of the subjects (8 drivers) will be exposed to the olfactory stimulus on the outbound half of their drive, and the auditory alerting stimulus on the inbound half of their drive. Of these eight, half (n = 4) will experience this condition during the first nighttime drive and the remaining half (n = 4) will experience it during the second nighttime drive.

Simulated nighttime driving scenario

The overnight, out-and-back drives (with and without drowsiness alarms/alerting stimuli) will be performed using the TruckSim. It is a high-fidelity ISIM Mark II Mobile Driving Simulator with the following features:

1. 21-mile looped freeway scenario with 2 and 3 lanes in each direction; 180° visual field of view; high resolution; programmable traffic controlled in direction, density and aggression.
2. full sized Freightliner FLD cab
3. 4 degrees-of-freedom motion platform (surge; heave; acceleration; shoulder rumble strips; road surface irregularities; etc.)
4. moving truck sound and vibration
5. vehicle instrument lights, and high and low beam exterior lights
6. interstate scenario includes multiple exits, rest area, flat test area, and runaway ramps

Drowsiness detection

An "on-line" drowsiness detection system based on the duration of eyelid closure of 80% or more (ignoring normal blinks) will be employed throughout both control and intervention driving conditions, using the basic observational criteria of PERCLOS[1]. The automated on-line PERCLOS system being developed by CMRI will be used. The cumulative total duration of time that eyelids are judged to be closed will serve as the primary biobehavioral drowsiness dependent variable for comparison between the control and intervention conditions to determine whether drowsiness feedback alarms and/or alerting stimuli reduce a driver's drowsiness. For the intervention conditions only (i.e., feedback visual alarms and alerting olfactory or auditory stimuli), eye closure drowsiness data will also form the basis for determining delivery of a drowsiness alarm.

Drowsiness alarms

Drowsy-driving feedback alarms will be audio and visual. Determination of the cumulative duration of time that the eyes are judged to be closed in order to trigger a drowsiness alarm will be based on analyses performed on data from the validation study of PERCLOS at the University of Pennsylvania.[2] Coherence between PERCLOS and vigilance lapses was greater for 20-minute periods of

[1] Weirwille, W.W. (1994). "Overview of Research on Driver Drowsiness Definition and Driver Drowsiness Detection." 14th International Technical Conference on Enhanced Safety of Vehicles (ESV), Munich, Germany.

[2] Dinges, D.F., Mallis, M.M., Maislin, G., and Powell, J.W. (1998). "Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and as the Basis for Alertness Management, Draft Final Report," submitted to US DOT.

testing than for 1-minute, 2-minute, 4-minute, 5-minute, and 10-minute periods. A moving-window period between 1-minute and 20-minutes will be used as the basis for delivering a drowsiness alarm to drivers, when a threshold level of drowsiness is detected (as determined by the automated CMRI PERCLOS algorithm).

Alerting Stimuli

Two of the more promising alerting stimuli will be delivered to subjects only after drowsiness has been present for a sustained period of time (to be determined). This drowsiness detection is based on preliminary studies and published literature reviewed to date. We anticipate these will consist of a peppermint [or menthol] odor and an auditory warning - "Take corrective action".

Rest break behaviors

Drivers will be permitted to determine the timing and duration of their rest breaks, with the exception that the rest break at the midpoint of the nighttime drive (i.e., at the turn-around point) will be permitted to last no more than 15 minutes and cannot include napping. A careful record will be kept of their voluntary rest breaks (inter-break driving interval, break timing, break duration, break activities) during both the control and intervention nighttime drives. A comparison of these activities between the two drives will provide the data needed to determine whether drowsiness alarms-alerting stimuli alter a driver's tendency to take breaks and the nature of the breaks.

Unsafe driving behaviors

Throughout the two nighttime drives, three types of unsafe driving behaviors will be recorded from the TruckSim: (1) time spent speeding; (2) off-roadway partial departures not involving crashes (i.e., into the breakdown lanes); and (3) crashes (i.e., complete off-roadway departures; collisions with moving and/or stationary objects).

Statistical Analysis

By using subjects as their own controls and counterbalancing the order of nighttime drive conditions, the effects of drowsiness feedback (i.e., alarms and alerting stimuli) can be made on all 16 subjects. A test of repeated assessment will be undertaken first, however, in the event that mere repeated exposure to the nighttime drive has marked effects on primary dependent variables independent of (or in interaction with) the intervention condition. If this is the case, statistical comparisons will be made between the 8 subjects who had the control condition first and the 8 who had the intervention condition first. Since there will be random assignment to order, this between-subject alternative analysis will ensure that the experiment yields meaningful comparisons even if the repeated exposure to the nighttime driving scenario has an unexpected effect.

The results of this experiment will tell us the effectiveness of an automated, on-line, PERCLOS-based, drowsiness-detection system with feedback in reducing driver drowsiness on a nighttime drive with time pressure. Within this broad question the study will also determine whether the nature of the feedback (i.e., alarm vs. alerting stimuli) influences the effectiveness and use of the system by drivers. Below this level, the project will also provide information on whether or not the visual feedback alarm and alerting stimulus (i.e., auditory alert or olfactory stimulus) will optimally reduce drowsiness and lead to safer driving behaviors. Consequently, in addition to resolving whether such a system actually reduces the duration and severity of drowsiness episodes while driving, the study will determine whether the deployment of such a system encourages drivers to engage in additional rest breaks to further promote alertness, or whether it encourages continuous driving with even fewer breaks. Similarly it will tell us whether unsafe driving practices are increased or decreased by the system. These latter questions are the most frequently cited issues of contention when the deployment of drowsy-driving technologies are discussed. This will be the first project to directly measure these outcomes and provide quantifiable data on these controversial issues.

The use of the TruckSim for the above experiment will provide a wealth of information without posing a threat to the driver or others on the roadways. From this study, information will be gained about drowsiness detection systems and feedback in reducing driver drowsiness.

Conclusions

Used properly, ground vehicle simulators can be an extremely effective tool for improving driver safety. The value of using simulators for training and human factor research has been clearly shown in aviation where simulators have been used for 30 years. The challenge in front of us is to apply simulation in an effective and economic manner to the ground transportation industry.

Realistic driving simulators are available today at a reasonable cost, and the cost is expected to fall sharply over the next few years. To achieve widespread and effective use of simulation, we must proceed quickly with a combination of applied and basic research initiatives focused on building the tools needed for widespread use of simulation.

Applied research programs can provide the rapid assessment of simulator effectiveness for training and other purposes. These efforts will provide a quantification of the cost and benefits for employing simulators for widespread training. These efforts can also quantify how well lessons are learned in a simulator (whether the lessons are driving skills or the value of a heads-up display) and how well these lessons transfer to the real world of the highway.

Basic research can, over a period of time, provide a more in-depth understanding of simulators and their effective application. Driving simulator technology is being engineered, even though developers are in unanimous agreement that they are proceeding without knowledge that should be guiding their activities. Driving simulators are currently being used for research and training, even though doubt exists about whether the products of these efforts will generalize to the natural environments targeted.